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April 18, 1968

C-MISSION (205/101) NAVIGATION ERROR ANALYSIS

By Navigation Analysis Section
TRW Systems Group

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By S. A. Fieglein
Navigation Analysis Section

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MISSION PLANNING AND ANALYSIS DIVISION
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MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Approved: J. C. McPherson
J. C. McPherson, Chief
Mathematical Physics Branch

Approved: Carl R. Huss
for John P. Mayer, Chief
Mission Planning and Analysis Division

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SYMBOLS

ANT	Antigua Island
BDA	Bermuda Island
CAL	Pt. Arguello, California
CNB	Canberra, Australia
CRO	Carnarvon, Australia
CSM	Command service module
CYI	Canary Island
EGL	Eglin Air Force Base
GET	Ground elapsed time
GWM	Guam Island
HAW	Kauai, Hawaii
MCC	Midcourse correction
MLA	Merritt Island
MSFN	Manned Spaceflight Network
NCC	"Corrective combination" for maneuver N
NSR	"Slow rate catch up" for maneuver N
PRE	Pretoria, South Africa
RCS	Reaction control system
S-IVB	Saturn IVB launch vehicle
SPS	Service propulsion system
TEX	Corpus Christi, Texas
TPI	Terminal phase initiation
WHS	White Sands, New Mexico

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1. SUMMARY

An error analysis of simulated observations by Manned Space Flight Network stations and the onboard sextant has been performed in order to determine the accuracy of the real-time and onboard orbit determination programs' solutions at specific times during the C-mission. Relative uncertainties in the CSM/S-IVB position and velocity vectors are presented during the interval from the phasing maneuver to the end of the CSM/S-IVB rendezvous. During other phases of the mission, the MSFN is tracking either a docked vehicle (CSM/S-IVB) or only the CSM. Estimated errors are presented at the burn initiation times during all phases of the C-mission.

During the rendezvous sequence, the maximum three sigma uncertainties, as defined in this study, in the estimated relative position and velocity magnitude occur at NCC-1 (1.6 nautical miles in position and 11.7 feet per second in velocity). At initiation of the remaining SPS burns, the three sigma uncertainties in the position and velocity magnitude of the CSM are less than 0.5 nautical mile and 3 feet per second, respectively.

2. INTRODUCTION

The purpose of this analysis is to compute an estimate of the accuracy with which the C-mission trajectories can be computed from the MSFN and onboard tracking data. This information is used to support a complete dispersion analysis for the C-mission which computes an estimate of the fuel required. The analysis simulates the data incorporation and filtering techniques which may be employed either onboard or on the ground.

The computer programs used for the analysis are described below:

a) TAPP IV generates an integrated trajectory which matches the reference trajectory described in Reference 1; performs a complete tracking simulation of the mission including the generation of vehicle rise-set times and tracking information matrices when given input tracking stations, their associated data types and rates, and the trajectory (Reference 3); and generates coordinate transformation and state transition matrices.

b) FASTAP I processes the TAPP IV tapes for two vehicles and forms a tape containing all information, state transition and coordinate transformation matrices for the mission.

c) MOFIT uses the information from the FASTAP I tape to compute the accuracies using a linear error analysis technique.

For all of the analysis, it was assumed that the real-time orbit determination scheme solved for three components of position and three components of velocity.

2.1 Error Model

The error sources considered in the generation of the ground tracking information matrices are the uncertainties in the drag k-factor and the earth's gravitational constant, the uncertainties in station location for each station, and the noise and bias on each data type. The error sources for onboard measurements include uncertainties in the drag k-factor, the earth's gravitational constant, the position and velocity of the S-IVB and the position and velocity of the CSM, platform misalignment, platform drift, and the noise and bias on each data type. Tables I and II (References 2, 4, and 5) list the one sigma (1σ) values of the systematic errors and the noise value (1σ) for ground and onboard data, respectively.

2.2 Tracking Data Descriptions

Simultaneous tracking for short intervals during the C-mission by two or more stations is operationally feasible.* However, for this analysis the selection of the stations used to simulate the tracking was limited by the criterion that two or more stations cannot track simultaneously. Therefore, at times when the vehicle would be visible to several stations, the station which would view the vehicle for the longest time is designated to track. A minimum elevation angle of five degrees was assumed for all ground-based stations.

The C-band stations were used to track the S-IVB and received range, azimuth angle, and elevation angle measurements at the rate of one set of measurements per 6 seconds. The S-band stations tracked the CSM and received two-way doppler and angle (X/Y) measurements at the rate of one measurement set per 6 seconds. During the periods when onboard tracking was simulated, the sextant was used as a high resolution telescope measuring a set of shaft and trunnion angles every 75 seconds.

The loss of tracking data due to tracking a tumbling S-IVB was not simulated in this analysis, however, a large area for the S-IVB was chosen to simulate the drag effects on a tumbling vehicle. Previous navigation studies conducted by MSC indicate that degraded tracking caused by S-IVB tumbling should not significantly affect orbit determination accuracy.

2.3 Mission Description and Tracking Schedule

The description of the mission will be discussed in three phases:

Phase I: Insertion to initial phasing maneuver

Phase II: Rendezvous sequence

Phase III: SPS burn 3 to reentry

Figure 1 is an event schedule which presents the order of the update and maneuvers.

2.3.1 Phase I. - The reference or lift-off date for this study is 1 August 1968, 17 hours, Greenwich mean time. The docked configuration is inserted into orbit and coasts until 1 hour 34 minutes, g. e. t., at which time there is an S-IVB vent maneuver. The vehicle then coasts until 2 hours 55 minutes, g. e. t., at which time the S-IVB and CSM are separated. At 3 hours 31 minutes, g. e. t., the CSM performs a small RCS phasing maneuver; a ground update is sent from Bermuda at 3 hours 10 minutes, g. e. t.

*Simultaneous tracking is feasible in that a C-band station may skin track the vehicle while an S-band station is tracking; two master stations cannot track simultaneously.

During the first part of this phase, USB stations are used to track the docked configuration. Subsequent to separation, the CSM is tracked by USB stations; the S-IVB will be tracked by C-band stations.

Figure 2 is a bar graph of tracking visibility during Phase I.

2.3.2 Phase II. - The rendezvous maneuvers begin with NCC-1 at 26 hours 18 minutes, g.e.t. Tracking begins three revolution prior to the update for NCC-1 which is sent from BDA at 25 hours 36 minutes, g.e.t. Another ground update is assumed sent from ANT at 27 hours 15 minutes, g.e.t., to determine the need for an NCC-2 maneuver. Since NCC-1 and NSR are coupled burns, no update was assumed prior to the NSR maneuver. Vehicle-to-vehicle sextant measurements are taken to determine the time of TPI and the midcourse correction (MCC) burn. Figure 3 is a bar graph of the MSFN tracking schedule during Phase II.

Since the onboard computer completely neglects the effects of drag, a 100 percent bias in the acceleration due to drag was considered. In this analysis, the nonzero mean (which accounts for this bias) associated with the covariance matrices formed using onboard data has been calculated. These means associated with the covariance matrices are given in Table V. For this analysis sixteen marks of sextant data are taken between NSR and TPI; seven marks are taken between TPI and MCC.

2.3.3 Phase III. - The remainder of the mission is a series of SPS burns beginning with the third SPS burn at 3 days 23 hours 36 minutes, g.e.t., and ending with reentry. For each SPS burn, tracking begins three revolutions prior to the time of update for the burn.

The update for the 3rd SPS burn was assumed to be sent from CNB at 3 days 23 hours 2 minutes, g.e.t.; for the 4th SPS burn from HAW at 5 days 0 hours 46 minutes, g.e.t.; for the 5th SPS burn from HAW at 7 days 1 hour 6 minutes, g.e.t.; for the 6th SPS burn from CNB at 10 days 18 hours 31 minutes, g.e.t.; for the 7th SPS burn from CNB at 9 days 20 hours 6 minutes, g.e.t.; for the 8th SPS burn from CNB at 10 days 18 hours 31 minutes, g.e.t. There is no time for a tracking update prior to reentry; however, the ground continues to track the spacecraft. The uncertainties presented for reentry target conditions are the uncertainties calculated prior to the 8th SPS burn propagated to nominal time of reentry. The uncertainties presented for the ground's knowledge of reentry are computed using the tracking data taken between the 8th SPS burn and reentry. Figure 4 contains bar graphs of the tracking visibility during Phase III.

3. RESULTS

The values presented in Table III for the uncertainties in the magnitudes of the estimated relative position and velocity vectors are defined as three sigma uncertainties. These values were calculated by taking the square root of the sum of the variances of each component of the relative vector and then multiplying the resulting value by three.

The uncertainties in the three components of position and the three components of velocity, which are presented in Table IV, are associated with a gaussian distribution of zero mean, except for the uncertainties listed for the TPI and MCC maneuvers. Since TPI and MCC are computed onboard, the means are nonzero (Section 2.3, Mission Description and Tracking Schedule). These means are listed with the associated covariance matrices in Table V.

4. CONCLUSIONS

1. The largest relative uncertainties are in the downrange position component and radial velocity component during the rendezvous phase. These large uncertainties are chiefly due to the 10 percent drag uncertainty associated with the S-IVB where drag is acting over an area of 1400 square feet.

2. The ground tracking network coverage appears adequate for performing all maneuvers; it is noted that good stateside coverage is necessary to lower uncertainties. The onboard measurements, however, barely improve on the a priori estimate of the vehicles' state vectors received from the ground.

3. Based on previous MSC studies, S-IVB tumbling should not significantly effect orbit determination accuracy.

Table I. One Sigma Values of MSFN Error Sources

USBS Tracking Accuracy

	Bias	Noise
X-Y Mount:	0.8 mrad	1.6 mrad
Two-way Doppler:	0.03 fps	0.02 fps

C-band Tracking Accuracy

Station	Type of C-band Radar	Azimuth Bias (mrad)	Azimuth Noise (mrad)	Elevation Bias (mrad)	Elevation Noise (mrad)	Range Bias (ft)	Range Noise (ft)
MLA	TPQ-18	0.3	0.15	0.3	0.15	40	20
ANT	FPQ-6	0.3	0.15	0.3	0.15	40	20
BDA	FPQ-6	0.3	0.15	0.3	0.15	40	20
CYI	MPS-26	2.0	1.0	2.0	1.0	120	60
PRE	MPS-25	0.4	0.2	0.4	0.2	60	30
CRO	FPQ-6	0.3	0.15	0.3	0.15	40	20
HAW	FPS-16	0.4	0.2	0.4	0.2	60	30
WHS	FPS-16	0.4	0.2	0.4	0.2	60	30
EGL	FPS-16	0.4	0.2	0.4	0.2	60	30

Table I. One Sigma Values of MSFN Error Sources (Continued)

Station	Station Location Uncertainties: Latitude (rad)	Longitude (rad)	Altitude (ft)
MLA	0.484813×10^{-5}	0.581776×10^{-5}	131.2
ANT	0.533295×10^{-5}	0.581776×10^{-5}	137.8
BDA	0.581776×10^{-5}	0.678739×10^{-5}	141.1
CYI	0.2230142×10^{-4}	0.2472549×10^{-4}	105.0
PRE	0.678739×10^{-5}	0.72722×10^{-5}	141.0
CRO	0.921145×10^{-5}	0.106659×10^{-4}	216.5
GWM	0.3102807×10^{-4}	0.319977×10^{-4}	105.0
HAW	0.678739×10^{-5}	0.775601×10^{-5}	141.1
WHS	0.484813×10^{-5}	0.581776×10^{-5}	131.2
TEX	0.484813×10^{-5}	0.533295×10^{-5}	131.2
EGL	0.484813×10^{-5}	0.581776×10^{-5}	131.2
CNB	0.921145×10^{-5}	0.106659×10^{-4}	216.5

K-factor or drag factor uncertainty: 0.10 (represents 10 percent of nominal drag)

Uncertainty in gravitational constant: 0.106×10^{12} (int ft)^3/sec^2

Table II. One Sigma Values* of Onboard Error Sources

	Noise	Bias
Error in vehicle-to-vehicle angular measurements:	0.2 mrad	0.2 mrad
**K-factor or drag factor uncertainty:	0.25 (represents 25% of nominal drag)	

*The 1σ errors for accelerometers and gyros are classified, but may be obtained from References 4 and 5.

**Assumed for this study

Table III. Three Sigma Values for Uncertainties in Position and Velocity

Event	Inertial CSM		Inertial S-IVB		Relative	
	$3\sigma_p$ (n mi)	$3\sigma_v$ (fps)	$3\sigma_p$ (n mi)	$3\sigma_v$ (fps)	$3\sigma_p$ (n mi)	$3\sigma_v$ (fps)
Separation	3.36	19.5	---	---	---	---
Initial phasing	0.221	1.07	0.329	2.03	0.323	1.80
NCC-1	0.249	1.52	1.81	12.9	1.64	11.7
NCC-2	0.178	1.01	0.797	5.7	0.724	5.1
NSR	0.227	1.23	1.15	8.4	1.03	7.5
TPI	2.41	17.0	2.42	16.4	1.32	10.1
MCC	2.48	14.9	2.46	14.3	0.321	2.37
SPS-3	0.170	1.86	---	---	---	---
SPS-4	0.195	1.53	---	---	---	---
SPS-5	0.129	0.900	---	---	---	---
SPS-6	0.350	3.00	---	---	---	---
SPS-7	0.170	0.966	---	---	---	---
SPS-8	0.378	2.35	---	---	---	---
Reentry-Target Conditions	0.371	2.66	---	---	---	---
Reentry-Ground Estimate	0.249	9.1				

Table IV. Three Sigma Values for Uncertainties in the Three Components of Position and Three Components of Velocity

Event	Separation	Phasing			NCC-1			NCC-2		
Vehicle	CSM/S-IVB	CSM	S-IVB	Relative	CSM	S-IVB	Relative	CSM	S-IVB	Relative
u^* (n mi)	0.774	0.066	0.282	0.271	0.055	0.232	0.178	0.045	0.087	0.070
v (n mi)	3.24	0.154	0.192	0.093	0.196	1.79	1.62	0.111	0.789	0.709
w (n mi)	0.479	0.143	0.259	0.149	0.143	0.094	0.130	0.133	0.062	0.125
$\dot{u}$ (fps)	19.0	0.880	1.15	0.645	1.29	12.7	11.5	0.673	5.64	5.06
$\dot{v}$ (fps)	4.03	0.405	1.61	1.61	0.351	1.04	1.09	0.299	0.295	0.212
$\dot{w}$ (fps)	1.86	0.456	0.660	0.470	0.907	0.647	0.849	0.691	0.723	0.782

Event	NSR			TPI			MCC			SPS-3
Vehicle	CSM	S-IVB	Relative	CSM	S-IVB	Relative	CSM	S-IVB	Relative	CSM
u (n mi)	0.044	0.174	0.181	0.458	0.298	0.296	0.325	0.359	0.245	0.064
v (n mi)	0.174	1.13	1.00	2.35	2.40	1.38	2.47	2.44	0.205	0.124
w (n mi)	0.138	0.107	0.136	0.196	0.051	0.189	0.101	0.094	0.036	0.097
$\dot{u}$ (fps)	1.03	8.31	7.46	16.8	16.3	9.93	14.8	14.2	2.06	0.807
$\dot{v}$ (fps)	0.263	0.713	0.514	2.09	1.55	1.32	1.10	1.25	0.799	0.473
$\dot{w}$ (fps)	0.627	0.377	0.662	1.47	0.748	1.26	0.972	0.495	0.839	1.59

*The coordinate system is described on the format page of Table III.

Table IV. Three Sigma Values for Uncertainties in the Three Components of Position and Three Components of Velocity (Continued)

Event Vehicle	SPS-4	SPS-5	SPS-6	SPS-7	SPS-8	Reentry Target Conditions	Reentry Ground Estimate
u (n mi)	0.043	0.040	0.071	0.046	0.045	0.043	0.124
v (n mi)	0.163	0.095	0.330	0.127	0.352	0.359	0.134
w (n mi)	0.097	0.078	0.091	0.103	0.131	0.083	0.170
$\dot{u}$ (fps)	1.06	0.662	2.28	0.719	2.23	2.44	6.48
$\dot{v}$ (fps)	0.332	0.310	0.536	0.308	0.251	0.331	5.01
$\dot{w}$ (fps)	1.02	0.507	1.09	0.565	0.703	1.0	4.01

Table V. Covariance Matrices (One Sigma)

Format for Covariance Matrices

$$
\begin{array}{llllll}
\sigma_{uu} & \sigma_{uv} & \sigma_{uw} & \sigma_{u\dot{u}} & \sigma_{u\dot{v}} & \sigma_{u\dot{w}} \\
 & \sigma_{vv} & \sigma_{vw} & \sigma_{v\dot{u}} & \sigma_{v\dot{v}} & \sigma_{v\dot{w}} \\
 & & \sigma_{ww} & \sigma_{w\dot{u}} & \sigma_{w\dot{v}} & \sigma_{w\dot{w}} \\
 & & & \sigma_{\dot{u}\dot{u}} & \sigma_{\dot{u}\dot{v}} & \sigma_{\dot{u}\dot{w}} \\
\text{symmetrical} & & & & \sigma_{\dot{v}\dot{v}} & \sigma_{\dot{v}\dot{w}} \\
 & & & & & \sigma_{\dot{w}\dot{w}}
\end{array}
$$

The coordinate system for the covariance matrices is described below:

u - is in the direction of the geocentric radius vector of the vehicle at the time of the event

v - is orthogonal to u, pointing downrange in the orbit plane

w - is mutually orthogonal to u and v, completing the right-handed system

The units for position and velocity are feet and feet per second, respectively. The relative covariance matrices are in the coordinates of the CSM. The means presented are in feet and feet per second.

Table V. (Continued)

Inertial Covariance of S-IVB/CSM

Separation

	1	2	3	4	5	6
1	2.4563368+06	-1.0256374+07	-1.0879744+06	9.9275424+03	-2.0993987+03	-2.1078324+02
2	-1.0256374+07	4.2993270+07	4.5075176+06	-4.1606990+04	8.7763215+03	8.9805626+02
3	-1.0879744+06	4.5075176+06	9.4409093+05	-4.4180807+03	9.1643631+02	-2.9109487+02
4	9.9275424+03	-4.1606990+04	-4.4180807+03	4.0278438+01	-8.4949868+00	-8.2206598-01
5	-2.0993987+03	8.7763215+03	9.1643631+02	-8.4949868+00	1.8077597+00	1.9495343-01
6	-2.1078324+02	8.9805626+02	-2.9109487+02	-8.2206598-01	1.9495343-01	3.8491957-01

Inertial Covariance of CSM Phasing

Maneuver

	1	2	3	4	5	6
1	1.8925970+04	-1.2637970+04	1.5241426+04	1.4836046+01	-1.1391521+01	-4.5677669+00
2	-1.2637970+04	9.6855009+04	-3.3866562+04	-9.0012099+01	1.6653075+01	5.8289717+00
3	1.5241426+04	-3.3866562+04	8.3903760+04	2.8956340+01	-1.4482898+01	-1.3296954+01
4	1.4836046+01	-9.0012099+01	2.8956340+01	8.6214092-02	-1.7265709-02	-5.6713916-03
5	-1.1391521+01	1.6653075+01	-1.4482898+01	-1.7265709-02	1.8226159-02	5.5457103-03
6	-4.5677669+00	5.8289717+00	-1.3296954+01	-5.6713916-03	5.5457103-03	2.3064605-02

Inertial Covariance of S-IVB Phasing

Maneuver

	1	2	3	4	5	6
1	3.2796533+05	-1.1040457+05	1.0592435+05	1.2948646+02	-3.0080539+02	-8.7234596+01
2	-1.1040457+05	1.5248527+05	-1.2905448+05	-1.4681597+02	1.0760649+02	2.0959643+01
3	1.0592435+05	-1.2905448+05	2.7445729+05	1.1787038+02	-9.7278942+01	-1.2892072+01
4	1.2948646+02	-1.4681597+02	1.1787038+02	1.4581022-01	-1.2405878-01	-2.7185820-02
5	-3.0080539+02	1.0760649+02	-9.7278942+01	-1.2405878-01	2.8863179-01	8.3452788-02
6	-8.7234596+01	2.0959643+01	-1.2892072+01	-2.7185820-02	8.3452788-02	4.8422889-02

Covariance of the Relative State Phasing

Maneuver

	1	2	3	4	5	6
1	3.0095196+05	-9.4778761+04	8.3322237+04	1.1288155+02	-2.9523881+02	-8.0881311+01
2	-9.4778761+04	3.5522285+04	-4.5895860+04	-4.0272554+01	9.3040369+01	2.1468482+01
3	8.3322237+04	-4.5895860+04	9.1177688+04	4.7613870+01	-8.1951332+01	-8.5199664+00
4	1.1288155+02	-4.0272555+01	4.7613870+01	4.6271092-02	-1.1078930-01	-2.7004557-02
5	-2.9523881+02	9.3040369+01	-8.1951332+01	-1.1078930-01	2.8963478-01	7.9302950-02
6	-8.0881311+01	2.1468482+01	-8.5199665+00	-2.7004558-02	7.9302950-02	2.4563491-02

Inertial Covariance of CSM

NCC-1

	1	2	3	4	5	6
1	1.2362873+04	-2.4467739+04	-2.7156590+02	2.1537606+01	-5.9106635+00	-5.7519297+00
2	-2.4467739+04	1.5741141+05	3.5486960+03	-1.6516069+02	2.0952426+01	1.4542543+01
3	-2.7156590+02	3.5486960+03	8.4240750+04	-8.5140073-01	4.6857108-01	7.3998365+01
4	2.1537606+01	-1.6516069+02	-8.5140073-01	1.8361690-01	-1.6599814-02	-6.8252520-03
5	-5.9106635+00	2.0952426+01	4.6857108-01	-1.6599814-02	1.3693419-02	9.3111373-03
6	-5.7519297+00	1.4542543+01	7.3998365+01	-6.8252520-03	9.3111373-03	9.1406947-02

Inertial Covariance of S-IVB

NCC-1

	1	2	3	4	5	6
1	2.2054641+05	-1.6702628+06	-1.9286957+04	1.9551285+03	-1.5414177+02	-7.8070455+01
2	-1.6702628+06	1.3161196+07	1.2786171+05	-1.5406638+04	1.1944461+03	5.9557291+02
3	-1.9286957+04	1.2786171+C5	3.6084199+04	-1.4843217+02	1.9947228+01	1.3570482+01
4	1.9551285+03	-1.5406638+04	-1.4843217+02	1.8042588+01	-1.3972227+00	-7.0037687-01
5	-1.5414177+02	1.1944461+C3	1.9947228+01	-1.3972227+00	1.1919232-01	5.9095567-02
6	-7.8070455+01	5.9557291+02	1.3570482+01	-7.0037687-01	5.9095567-02	4.6545332-02

Covariance of Relative State

NCC-1

	1	2	3	4	5	6
1	1.3052700+05	-1.1770998+06	-1.0233101+04	1.3725583+03	-1.3229302+02	-5.0005988+01
2	-1.1770998+06	1.0788139+07	8.0661110+04	-1.2592193+04	1.1914895+03	4.4660005+02
3	-1.0233101+04	8.0661110+04	6.9564318+04	-8.7450196+01	1.1327169+01	5.1041402+01
4	1.3725583+03	-1.2592193+04	-8.7450196+01	1.4703794+01	-1.3888659+00	-5.1252552-01
5	-1.3229302+02	1.1914895+03	1.1327169+01	-1.3888659+00	1.3416457-01	5.1434733-02
6	-5.0005989+01	4.4660005+02	5.1041402+01	-5.1252552-01	5.1434733-02	8.0097325-02

Inertial Covariance of CSM

NCC-2

	1	2	3	4	5	6
1	8.1933491+03	1.2144279+03	6.0893265+03	3.7616996+00	-1.9568306+00	1.9301076-01
2	1.2144279+03	5.0749847+04	1.5767629+03	-4.7202580+01	2.3744953-01	7.4864816+00
3	6.0893265+03	1.5767629+03	7.2629039+04	4.5822909+00	-9.6293031+00	-4.4121954+01
4	3.7616996+00	-4.7202580+01	4.5822909+00	5.0526094-02	-4.7488443-03	-4.7644253-03
5	-1.9568306+00	2.3744953-01	-9.6293031+00	-4.7488443-03	9.9004678-03	-3.8321108-04
6	1.9301076-01	7.4864816+00	-4.4121954+01	-4.7644253-03	-3.8321108-04	5.3101794-02

Inertial Covariance of S-IVB

NCC-2

	1	2	3	4	5	6
1	3.1009345+04	-2.4917655+05	-1.4680196+03	2.9484236+02	-6.4202306+00	-1.6978259+01
2	-2.4917655+05	2.5598435+06	8.7439355+03	-3.0061037+03	6.4538464+01	1.7934585+02
3	-1.4680196+03	8.7439355+03	1.5756023+04	-1.0336992+01	-7.3017025-01	-1.3954563+01
4	2.9484236+02	-3.0061037+03	-1.0336992+01	3.5339195+00	-7.6525034-02	-2.1152828-01
5	-6.4202306+00	6.4538464+01	-7.3017025-01	-7.6525034-02	9.6624484-03	6.4229632-03
6	-1.6978259+01	1.7934585+02	-1.3954563+01	-2.1152828-01	6.4229632-03	5.8034430-02

Covariance of Relative State

NCC-2

	1	2	3	4	5	6
1	2.0211846+04	-1.8154462+05	2.3213258+03	2.1730670+02	-6.1186017+00	-1.4314590+01
2	-1.8154462+05	2.0661595+06	6.8226951+04	-2.4197029+03	1.8905001+01	1.5163070+02
3	2.3213258+03	6.8226949+04	6.3747662+04	-7.3886792+01	-9.1576655+00	-3.2811540+01
4	2.1730670+02	-2.4197029+03	-7.3886793+01	2.8417347+00	-2.6443041-02	-1.7530302-01
5	-6.1186017+00	1.8905002+01	-9.1576655+00	-2.6443042-02	4.9980904-03	3.4659632-03
6	-1.4314590+01	1.5163070+02	-3.2811540+01	-1.7530302-01	3.4659632-03	6.7875708-02

Inertial Covariance of CSM

NSR

	1	2	3	4	5	6
1	7.9332776+03	-1.3823601+04	2.5665981+03	1.2114119+01	-8.2345018-01	-1.8090134+00
2	-1.3823601+04	1.2471095+05	9.8022429+03	-1.1896535+02	1.1706992+01	2.9569111+01
3	2.5665981+03	9.8022429+03	7.8180907+04	-7.5241569+00	-1.8078115+00	3.8789257+01
4	1.2114119+01	-1.1896535+02	-7.5241569+00	1.1899872-01	-1.0071934-02	-2.2783899-02
5	-8.2345018-01	1.1706992+01	-1.8078115+00	-1.0071934-02	7.6863682-03	4.7438101-03
6	-1.8090134+00	2.9569111+01	3.8789257+01	-2.2783899-02	4.7438101-03	4.3704075-02

Inertial Covariance of S-IVB

NSR

	1	2	3	4	5	6
1	1.2348404+05	-7.8315022+05	-2.6257519+04	9.4721890+02	-7.6004642+01	1.9771289+01
2	-7.8315022+05	5.2618229+06	1.8447240+05	-6.3545464+03	5.0999710+02	-1.3172532+02
3	-2.6257519+04	1.8447240+05	4.6605242+04	-2.2256418+02	1.9505674+01	-5.8005200+00
4	9.4721890+02	-6.3545464+03	-2.2256418+02	7.6805176+00	-6.1756075-01	1.5901109-01
5	-7.6004642+01	5.0999710+02	1.9505674+01	-6.1756075-01	5.6545682-02	-1.2660214-02
6	1.9771289+01	-1.3172532+02	-5.8005200+00	1.5901109-01	-1.2660214-02	1.5768366-02

Covariance of Relative State

NSR

	1	2	3	4	5	6
1	1.3485707+05	-7.4037959+05	-1.6138134+04	9.0552668+02	-6.1454329+01	3.1876314+01
2	-7.4037959+05	4.1360381+06	1.1977084+05	-5.0546241+03	3.3000956+02	-1.6116835+02
3	-1.6138134+04	1.1977084+05	7.6046672+04	-1.3980307+02	5.2467200+00	2.3406015+01
4	9.0552668+02	-5.0546241+03	-1.3980307+02	6.1886706+00	-4.0152770-01	2.1155584-01
5	-6.1454329+01	3.3000956+02	5.2467200+00	-4.0152770-01	2.9397168-02	-1.2801197-02
6	3.1876314+01	-1.6116835+02	2.3406015+01	2.1155584-01	-1.2801197-02	4.8714565-02

Inertial Covariance of CSM

TPI

	1	2	3	4	5	6
1	8.6021560+05	-3.5880940+06	-1.2207282+04	4.2968741+03	-6.3338873+02	-2.4999945+01
2	-3.5880940+06	2.2735663+07	1.2984312+05	-2.6685269+04	2.4714398+03	2.4758755+02
3	-1.2207282+04	1.2984312+05	1.5828576+05	-1.5683631+02	4.3341646+00	-3.6416693+01
4	4.2968741+03	-2.6685269+04	-1.5683631+02	3.1486551+01	-2.9314584+00	-3.0558946-01
5	-6.3338873+02	2.4714398+03	4.3341646+00	-2.9314584+00	4.8922363-01	9.6154470-03
6	-2.4999945+01	2.4758755+02	-3.6416693+01	-3.0558946-01	9.6154470-03	2.3986013-01

Means Associated with Inertial Covariance of CSM

TPI

	1
1	-2.6567267+03
2	5.4581244+03
3	9.9189810+00
4	-7.1842996+00
5	1.9967579+00
6	1.3523940-02

Inertial Covariance of S-IVB

TPI

	1	2	3	4	5	6
1	3.6449552+05	-1.4377335+06	1.0406517+03	1.5689711+03	-3.0817516+02	2.2783507+01
2	-1.4377335+06	2.3641907+07	1.1948119+05	-2.6440015+04	1.1235980+03	1.8429922+02
3	1.0406517+03	1.1948119+05	1.0620969+04	-1.3926449+02	-2.2629569+00	-8.3840320-01
4	1.5689711+03	-2.6440015+04	-1.3926449+02	2.9686537+01	-1.2020128+00	-2.3091865-01
5	-3.0817516+02	1.1235980+03	-2.2629569+00	-1.2020128+00	2.6550672-01	-2.4071832-02
6	2.2783507+01	1.8429922+02	-8.3840320-01	-2.3091865-01	-2.4071832-02	6.2129725-02

Means Associated with Inertial Covariance of S-IVB

TPI

	1
1	-1.8111841+03
2	3.5334530+03
3	6.5759448+00
4	-4.7232506+00
5	1.3494636+00
6	9.2863232-03

Covariance of Relative State

TPI

	1	2	3	4	5	6
1	3.6000649+05	-1.4693036+06	-3.7782460+03	1.7557552+03	-2.5796203+02	-1.2998255+01
2	-1.4693036+06	7.7929110+06	-9.8459277+03	-9.2257924+03	1.1454289+03	5.1713199+01
3	-3.7782460+03	-9.8459277+03	1.4730278+05	1.0426598+01	1.4294337+00	-3.6787260+01
4	1.7557552+03	-9.2257924+03	1.0426600+01	1.0961838+01	-1.3541944+00	-5.6911804-02
5	-2.5796203+02	1.1454289+03	1.4294337+00	-1.3541944+00	1.9301509-01	1.0267853-02
6	-1.2998255+01	5.1713199+01	-3.6787260+01	-5.6911805-02	1.0267853-02	1.7735266-01

Means Associated with Covariance of Relative State

TPI

	1
1	-8.5747569+02
2	1.9185748+03
3	7.4403377+00
4	-2.4656401+00
5	6.3135257-01
6	1.0442375-03

Inertial Covariance of CSM

MCC

	1	2	3	4	5	6
1	4.3324396+05	2.3965809+06	6.5340268+03	-2.2845381+03	-2.1300989+02	-7.5860213+00
2	2.3965809+06	2.4953552+07	1.2505584+05	-2.4539699+04	-7.0341264+02	-7.4405830+00
3	6.5340268+03	1.2505584+05	4.1961437+04	-1.4187454+02	6.1687688-01	2.3491009+01
4	-2.2845381+03	-2.4539699+04	-1.4187454+02	2.4480499+01	6.0082069-01	-3.9857549-03
5	-2.1300989+02	-7.0341264+02	6.1687688-01	6.0082069-01	1.3557851-01	1.4090661-03
6	-7.5860213+00	-7.4405830+00	2.3491009+01	-3.9857549-03	1.4090661-03	1.0503147-01

Means Associated with Inertial Covariance of CSM

MCC

	1
1	-1.2262224+03
2	6.9016808+03
3	-4.8583951+00
4	-7.4372433+00
5	1.1977349+00
6	9.0445655-03

Inertial Covariance of S-IVB

MCC

	1	2	3	4	5	6
1	5.2787574+05	2.4206219+06	2.3967258+04	-2.2174340+03	-2.7347529+02	7.1148414-01
2	2.4206219+06	2.4364590+07	1.3886498+05	-2.3259310+04	-6.6241092+02	-2.0232485+01
3	2.3967258+04	1.3886498+05	3.6206982+04	-1.5327968+02	-3.8606302+00	1.8535998+01
4	-2.2174340+03	-2.3259310+04	-1.5327968+02	2.2414637+01	5.3407935-01	1.5281989-02
5	-2.7347529+02	-6.6241092+02	-3.8606302+00	5.3407935-01	1.7452449-01	3.4720165-04
6	7.1148414-01	-2.0232485+01	1.8535998+01	1.5281989-02	3.4720165-04	2.7231707-02

Means Associated with Inertial Covariance of S-IVB

MCC

1	-1.4076872+03
2	6.6972128+03
3	3.9394195+00
4	-6.9060263+00
5	1.2681806+00
6	4.9074925-04

Covariance of Relative State

MCC

	1	2	3	4	5	6
1	2.4619798+05	2.0714758+05	-1.1808512+04	-3.2468326+02	-1.3044162+02	-3.4088694+00
2	2.0714758+05	1.7241661+05	-9.6418004+03	-2.8275555+02	-1.1627704+02	-1.3567281+00
3	-1.1808512+04	-9.6418004+03	5.3859401+03	1.3816711+01	5.5570938+00	5.4729324+00
4	-3.2468326+02	-2.8275555+02	1.3816711+01	4.7378471-01	1.8013662-01	-4.1101526-03
5	-1.3044162+02	-1.1627704+02	5.5570938+00	1.8013662-01	7.0929360-02	-2.3210131-03
6	-3.4088694+00	-1.3567281+00	5.4729324+00	-4.1101526-03	-2.3210131-03	7.8180004-02

Means Associated with Covariance of Relative State

MCC

	1
1	1.8738844+02
2	2.0571600+02
3	-9.1454881+0C
4	-5.3009796-01
5	-6.4336181-C2
6	8.1803992-03

Inertial Covariance of CSM

SPS-3

	1	2	3	4	5	6
1	1.6784497+04	-1.2501963+04	6.6347765+03	6.6844972+00	-1.3358805+01	-6.7180108+00
2	-1.2501963+04	6.3063307+04	-4.7480825+03	-6.4351138+01	1.1220857+01	7.2465607+00
3	6.6347765+03	-4.7480825+03	3.8890743+04	6.1278049+00	-5.7026248+00	8.0423931+01
4	6.6844972+00	-6.4351138+01	6.1278049+00	7.2465219-02	-3.6396979-03	6.4896423-03
5	-1.3358805+01	1.1220857+01	-5.7026248+00	-3.6396979-03	2.4909630-02	5.0182010-03
6	-6.7180108+00	7.2465607+00	8.0423931+01	6.4896423-03	5.0182010-03	2.8419565-01

Inertial Covariance of CSM

SPS-4

	1	2	3	4	5	6
1	7.6505146+03	-8.0665419+03	5.7817735+02	6.3600682+00	-2.5356979+00	-7.0512933+00
2	-8.0665419+03	1.0862906+05	1.0575853+03	-1.1418954+02	4.0559760+00	1.4295430+00
3	5.7817735+02	1.0575853+03	3.8943295+04	-1.4440022+00	-1.6163964+00	4.8784045+01
4	6.3600682+00	-1.1418954+02	-1.4440022+00	1.2501787-01	-1.2982553-03	2.3504291-03
5	-2.5356979+00	4.0559760+00	-1.6163964+00	-1.2982553-03	1.2223133-02	4.4398826-03
6	-7.0512933+00	1.4295430+00	4.8784045+01	2.3504291-03	4.4398826-03	1.1518754-01

Inertial Covariance of CSM

SPS-5

	1	2	3	4	5	6
1	6.6710332+03	-3.4326638+03	4.1088078+02	3.5799602+00	-1.4043753+00	-1.5283009+00
2	-3.4326638+03	3.7112138+04	2.8366242+03	-4.1073254+01	3.5743570+00	7.3877752+00
3	4.1088078+02	2.8366242+03	2.5263208+04	-4.1975019+00	-5.5601314-01	1.6111218+01
4	3.5799602+00	-4.1073254+01	-4.1975019+00	4.8674919-02	-3.1008137-03	-8.8946875-03
5	-1.4043753+00	3.5743570+00	-5.5601314-01	-3.1008137-03	1.0688514-02	-1.2320887-03
6	-1.5283009+00	7.3877752+00	1.6111218+01	-8.8946875-03	-1.2320887-03	2.8519124-02

Inertial Covariance of CSM

SPS-6

	1	2	3	4	5	6
1	2.0905323+04	-1.9139469+04	3.4831631+03	1.4908734+01	-1.7977335+01	-2.9031555+01
2	-1.9139469+04	4.4691669+05	-4.5945615+03	-5.0679091+02	-7.2693737+00	-1.7350657+01
3	3.4831631+03	-4.5945615+03	3.4061610+04	5.8139259+00	-1.8439744+00	8.4787738+01
4	1.4908734+01	-5.0679091+02	5.8139259+00	5.7956769-01	1.6748072-02	3.8628010-02
5	-1.7977335+01	-7.2693737+00	-1.8439744+00	1.6748072-02	3.1960694-02	3.8329656-02
6	-2.9031555+01	-1.7350657+01	8.4787738+01	3.8628010-02	3.8329656-02	4.0250515-01

Inertial Covariance of CSM

SPS-7

	1	2	3	4	5	6
1	8.7390502+03	-6.3660511+03	-7.9758268+03	6.6821383+00	-1.9473960+00	-5.6532170-01
2	-6.3660511+03	6.6191974+04	1.1907947+04	-6.0864566+01	1.3899436+01	-6.7168291+00
3	-7.9758268+03	1.1907947+04	4.3907651+04	-1.3083437+01	8.5938036+00	2.3176962+01
4	6.6821383+00	-6.0864566+01	-1.3083437+01	5.7426988-02	-1.3584829-02	5.0669130-03
5	-1.9473960+00	1.3899436+01	8.5938036+00	-1.3584829-02	1.0602714-02	1.7075320-03
6	-5.6532170-01	-6.7168291+00	2.3176962+01	5.0669130-03	1.7075320-03	3.5518117-02

Inertial Covariance of CSM

SPS-8

	1	2	3	4	5	6
1	8.2105631+03	-4.0111317+04	-1.6955296+02	4.2522614+01	4.7778538-01	-1.4910453+00
2	-4.0111317+04	5.0926318+05	1.0962882+04	-5.2689651+02	8.2325443+00	-2.7846582+01
3	-1.6955296+02	1.0962882+04	7.0787972+04	-7.4208324+00	2.6548362+00	-3.2871234+01
4	4.2522614+01	-5.2689651+02	-7.4208324+00	5.5195679-01	-9.3430372-03	1.8438097-02
5	4.7778538-01	8.2325443+00	2.6548362+00	-9.3430372-03	6.9800248-03	-4.7766823-04
6	-1.4910453+00	-2.7846582+01	-3.2871234+01	1.8438097-02	-4.7766823-04	5.4934882-02

Inertial Covariance of CSM

Reentry-Target Conditions

	1	2	3	4	5	6
1	7.7315538+03	-8.4867390+03	-3.2307227+03	1.2331192+01	-1.5407334+00	-9.4201487+00
2	-8.4867390+03	5.2830439+05	-4.3770394+03	-5.8907242+02	-2.8071709+01	-2.3269434+01
3	-3.2307227+03	-4.3770394+03	2.8160578+04	3.0828097+00	4.1960245+00	-1.9903556+01
4	1.2331192+01	-5.8907242+02	3.0828097+00	6.6161194-01	2.8170090-02	1.7352643-02
5	-1.5407334+00	-2.8071709+01	4.1960245+00	2.8170090-02	1.2155403-02	7.3479371-03
6	-9.4201487+00	-2.3269434+01	-1.9903556+01	1.7352643-02	7.3479371-03	1.1376080-01

Inertial Covariance of CSM

Reentry-Ground Estimate

	1	2	3	4	5	6
1	6.2845366+04	-3.4109011+04	-3.2140703+04	2.2275304+02	-1.1908917+02	-1.0806527+02
2	-3.4109011+04	7.3804993+04	6.6549713+04	-5.2998520+02	3.7980198+02	8.0097385+00
3	-3.2140703+04	6.6549713+04	1.1843525+05	-5.1887418+02	3.9061445+02	9.9655945+01
4	2.2275304+02	-5.2998520+02	-5.1887418+02	4.6656329+00	-3.5345743+00	5.3443703-01
5	-1.1908917+02	3.7980198+02	3.9061445+02	-3.5345743+00	2.7919520+00	-7.2824153-01
6	-1.0806527+02	8.0097385+00	9.9655945+01	5.3443703-01	-7.2824153-01	1.7843252+00

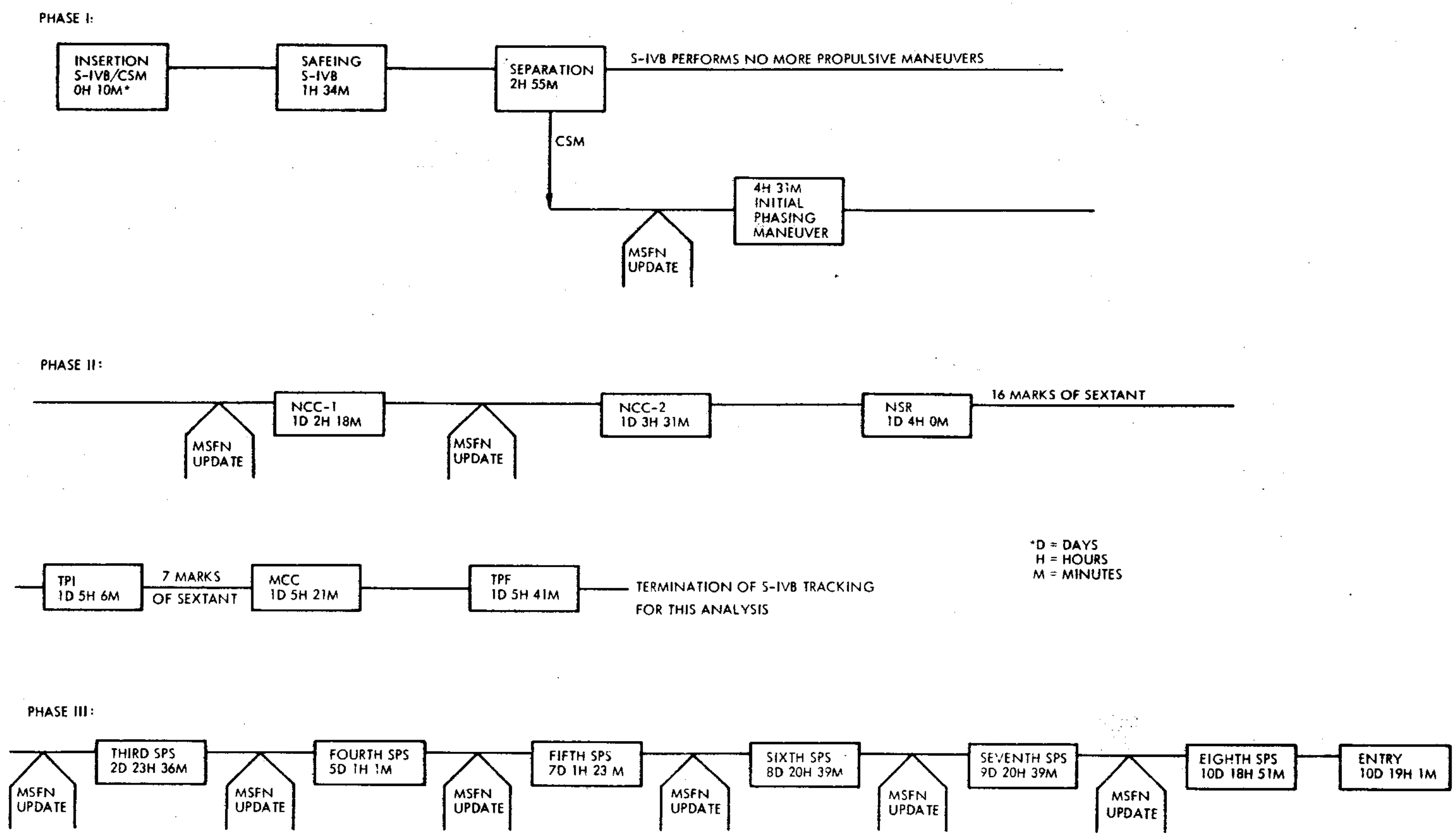


Figure 1. Event Schedule

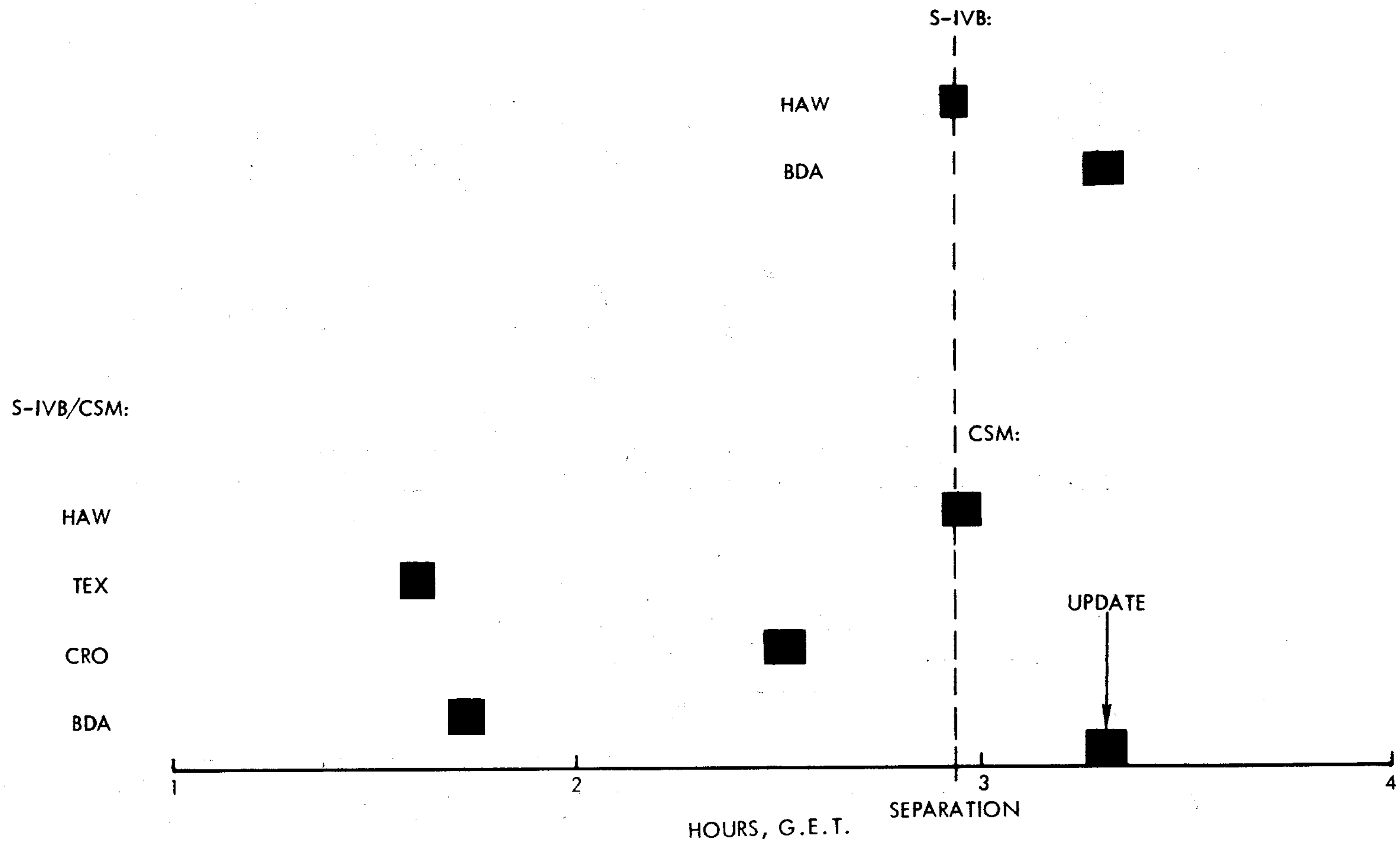


Figure 2. MSFN Tracking Schedule for Phase 1

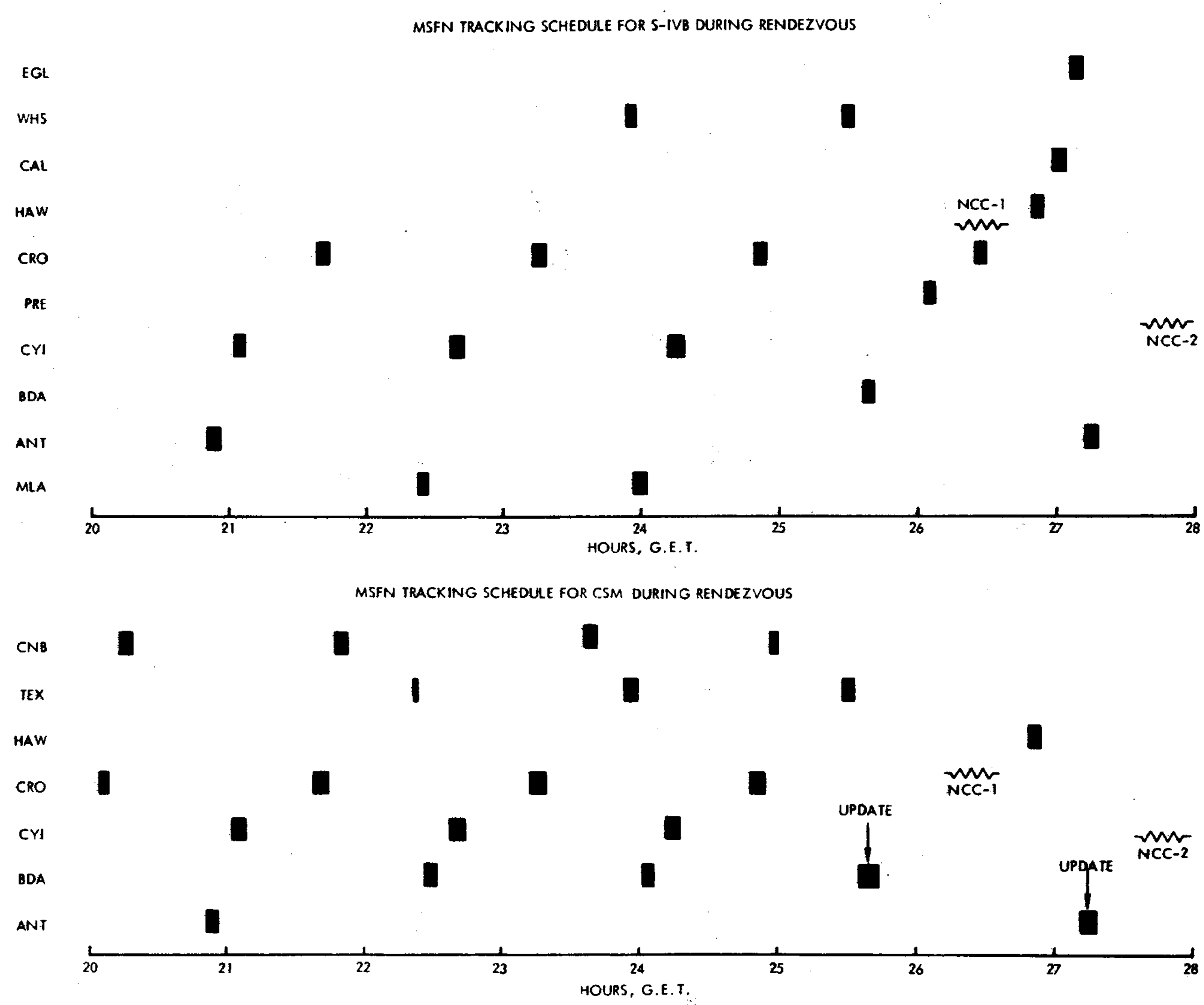


Figure 3. MSFN Tracking Schedule for Phase II

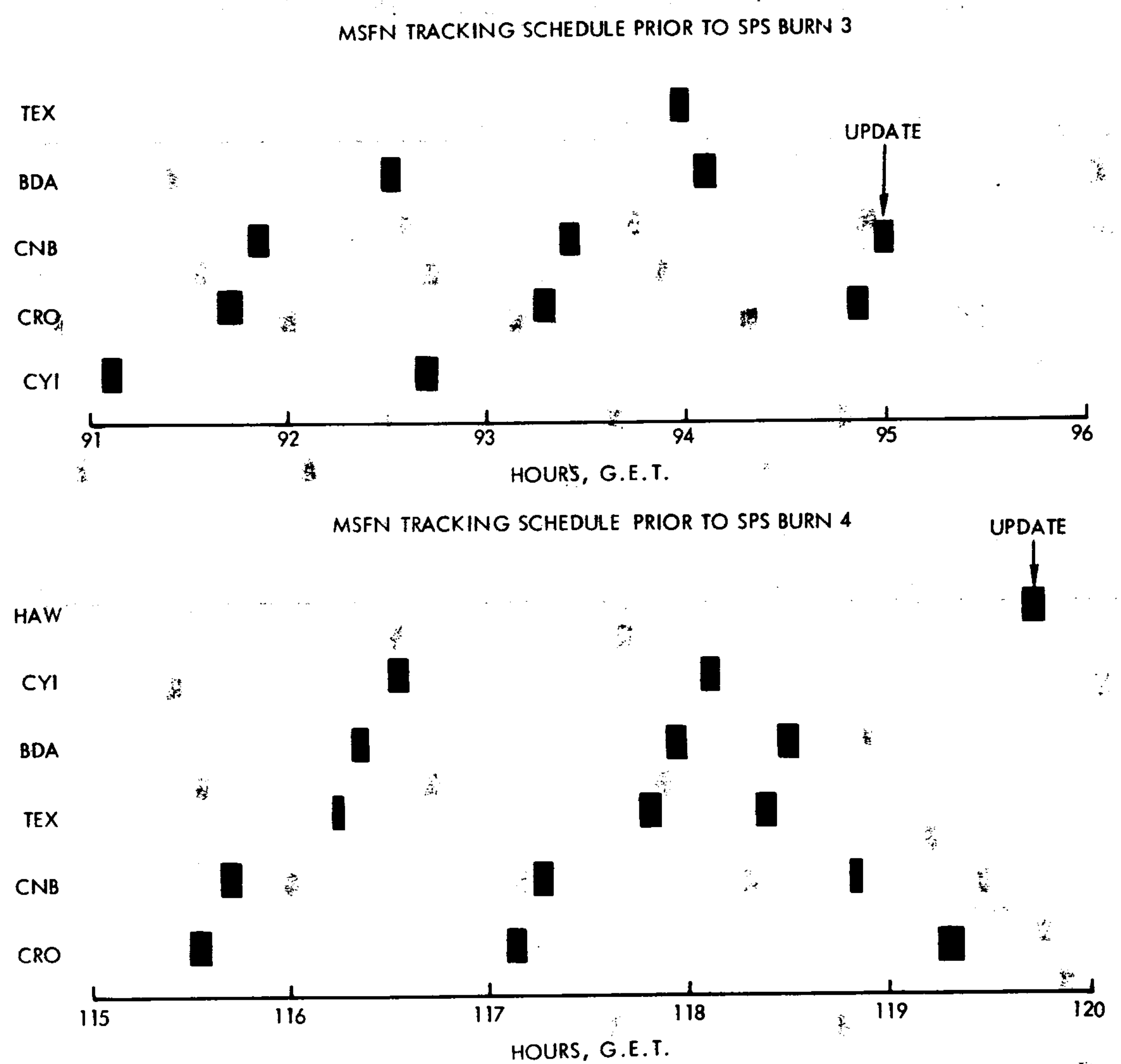


Figure 4. MSFN Tracking Schedule for Phase III

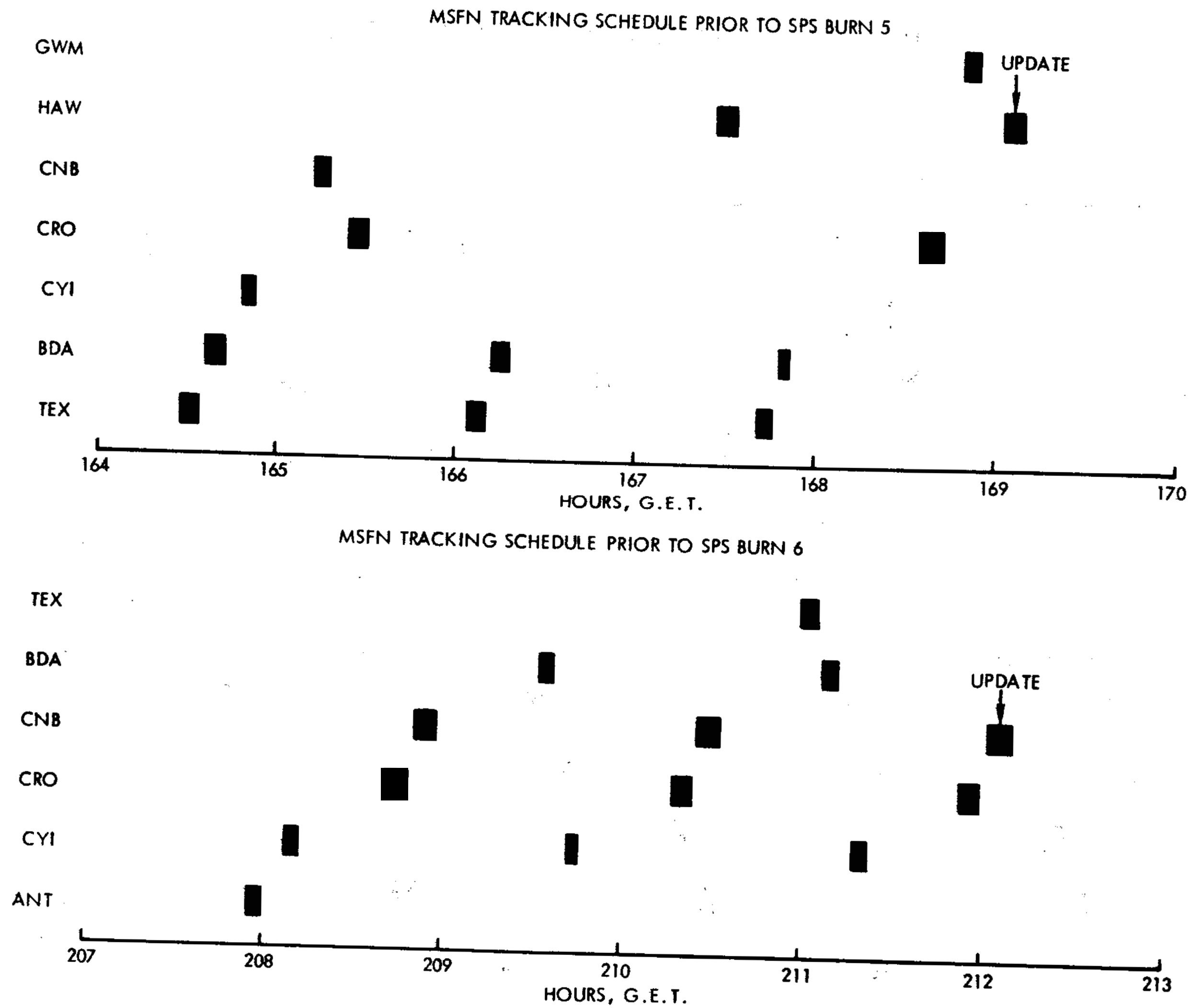
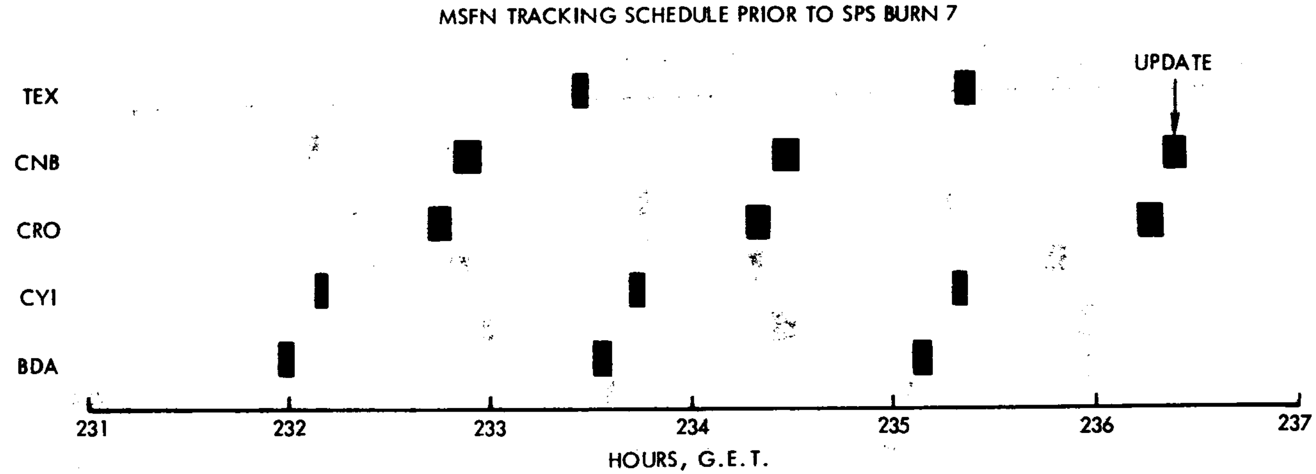


Figure 4. MSFN Tracking Schedule for Phase III (Continued)



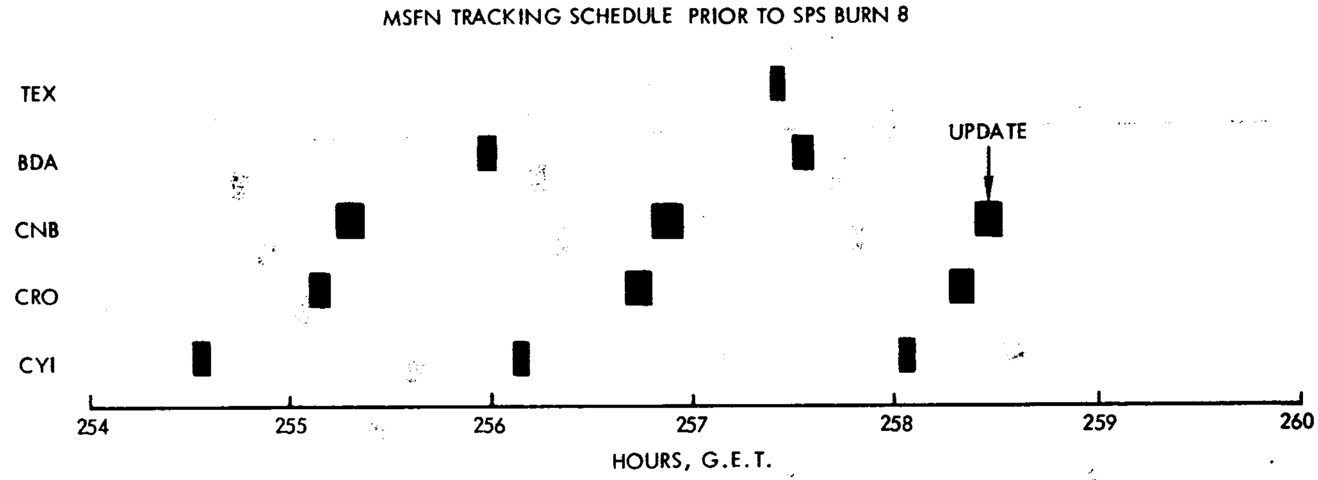


Figure 4. MSFN Tracking Schedule for Phase III (Continued)

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